PHOSPHATE ROCK MINING IN SOUTHEASTERN IDAHO

By D. W. Butner

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D. W. Butner[1/]

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1/ Mining engineer, Albany Branch, Bureau of Mines.

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INTRODUCTION AND SUMMARY

This report is concerned with the conditions affecting the methods and costs of mining phosphate rock in that part of the western phosphate field that is in Bear Lake and Caribou Counties in southeastern Idaho (see fig. 1). The area was selected because it contains most of the known phosphate reserve and because its geology has been studied more extensively than that of other sections.

Deposits of phosphate rock on public land may be leased from the Government under the terms of the Mineral Leasing Act of 1920, subject to the regulations of the Bureau of Land Management. Public interest in phosphate production is growing, as shown by an increasing number of applications for leases.

Two mines are being operated steadily for the production of phosphate rock by companies that have also the necessary processing plants for the manufacture of fertilizer. Total western phosphate-rock production in 1947 is reported by the Economics Statistics and Division of the Federal Bureau of Mines to have been 1,193,000 long tons, mined in Idaho, Montana, and Wyoming. The average grade was 30.7 percent of contained phosphorus pentoxide (P_2O_5); the average value at the mines was $5.67 per long ton. Idaho contributed 905,000 tons, or somewhat more than 75 percent of western production. Western fertilizer plants took 23 percent of total production; 76 percent was exported. Strip mining accounted for 75 percent of the Idaho tonnage; the remainder was stoped from underground workings.

Rock must contain a minimum of 30 percent P_2O_5 to be commercially useful for the production of superphosphate fertilizer by current acid treatment methods. Research by corporations and Government agencies has been directed toward the use of lower-grade ore. So far, only by smelting can rock containing as little as 25 percent P_2O_5 be used economically. Any development of processing or use pattern that would render the mining of, say, 20 percent rock profitable would have important effects in reducing the unit cost of mining.

In the search for metallurgical improvements, consideration should be given to the saving of valuable components of the rock, such as vanadium and fluorine, both of which are present in the beds.

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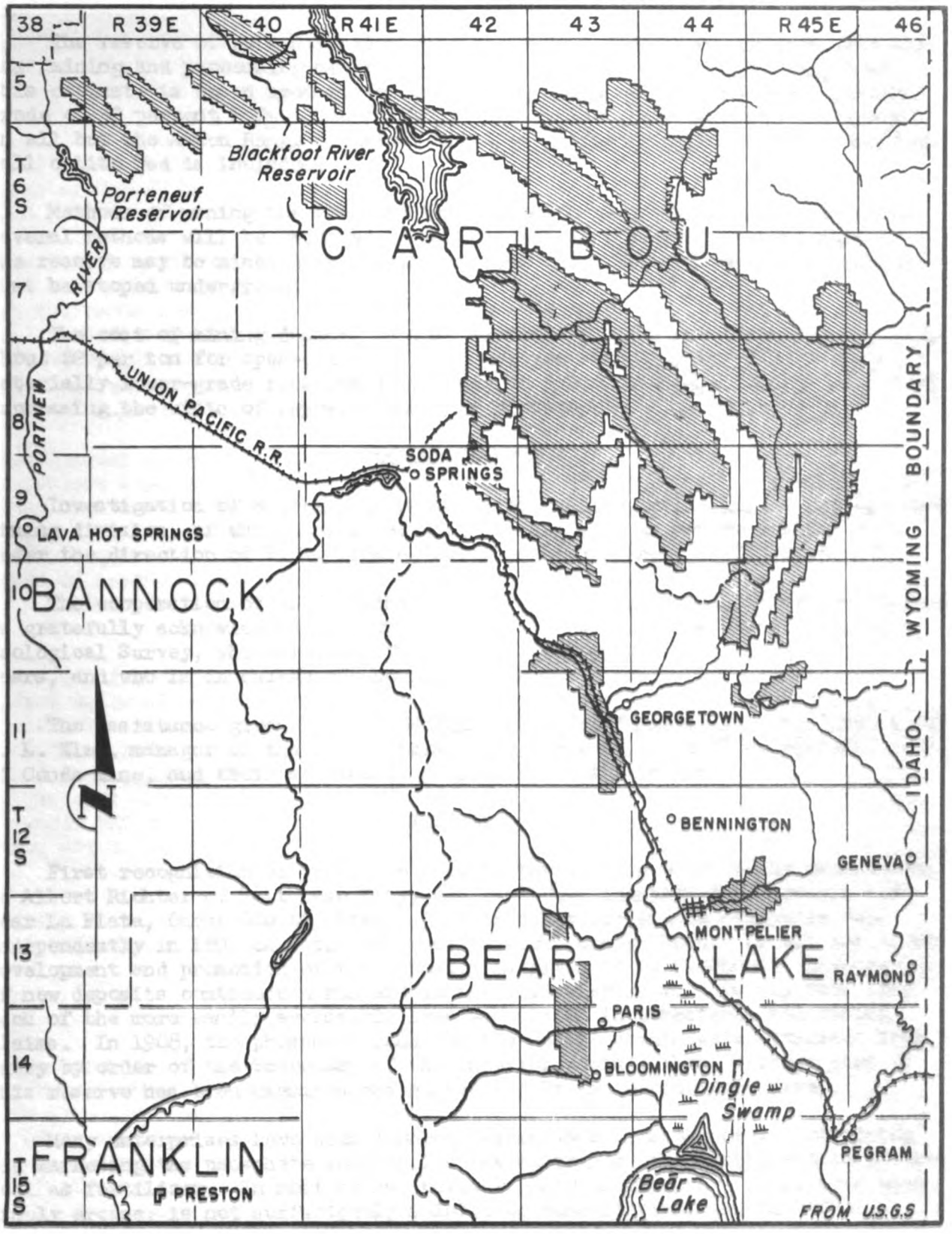

Figure 1. – Phosphate reserve areas in southeastern Idaho.

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The reserve of phosphate rock in southeastern Idaho available to present-day mining and processing methods is estimated to be 230,000,000 long tons. This estimate is based upon an assumed mining depth of 500 feet and a minimum grade of 30 percent P_2O_5. The footwall oolite bed alone has been considered in all but the Aspen Range division; there an estimated tonnage in the hanging-wall oolite bed is included.

Methods of mining the ore must be adapted to conditions in each deposit. Several methods will be required to exploit all of the ore. A small part of the reserve may be mined by stripping or open cut. The greater part, however, must be stoped underground.

The cost of mining depends on many variable conditions; it will range from about $2 per ton for open-pit work to $5 per ton for stoping. A demand for materially lower-grade rock has a tendency to reduce the unit cost of mining by increasing the width of deposits that can be mined.

ACKNOWLEDGMENTS

Investigation of mineral resources is one of the activities of the Bureau's mining division, of which Lowell B. Moon is chief. This report was prepared under the direction of S. H. Lorain, chief, Albany Branch, mining division.

The cooperation of A. E. Weissenborn, regional geologist, Geological Survey, is gratefully acknowledged. Special thanks are due V. E. McKelvey, geologist, Geological Survey, who has been studying the western phosphates for several years, and who is in charge of the field work.

The assistance given by G. A. McHugh, manager of mining for the Simplot Co., D. L. King, manager of the San Francisco Chemical Co., and T. C. Russell, manager of Conda mine, and their staffs, is acknowledged with thanks.

HISTORY

First recognition of phosphate rock in the west is ascribed by Mansfield[2/] to Albert Richter of Salt Lake City, who, in 1889, identified phosphatic beds near La Plata, Cache County, Utah. R. A. Pidcock recognized phosphate rock independently in 1897 on Woodruff Creek in Rich County, Utah. Credit for first development and promotion of the deposits is given to C. C. Jones. Discovery of new deposits continued northward in the following years. During this time much of the more easily accessible land was staked in homesteads and mining claims. In 1908, the phosphate lands on the public domain were withdrawn from entry by order of the Secretary of the Interior. Since then, a large part of this reserve has been examined and classified by the Geological Survey.

Many enterprises have been launches since 1900 with the object of mining and marketing the phosphate rock in its raw state for direct application to the soil as fertilizer. In most soils, however, natural phosphate rock, even when finely ground, is not sufficiently soluble to benefit plant growth notably.

2/ Mansfield, G. R., Geography, Geology, and Mineral Resources of Part of Southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927, p. 292.

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The result was short life for the mining ventures. Those at Cokeville, Wyo., Paris Canyon, Idaho, Georgetown Canyon, Idaho, and the early work at Waterloo Hill in Montpelier Canyon, Idaho, were among the stronger of the early operations (figs. 1 and 2).

In 1920, the Anaconda Copper Mining Co. opened the deposit at Conda in the Aspen Range, near Soda Springs, Idaho. This was a new type of phosphate enterprise in the western field. The company had, at its smelter at Anaconda, Mont., sulfuric acid, a byproduct of the treatment of Butte sulfide ore. From the acid and phosphate rock, the copper company made a high-grade phosphate fertilizer. After finding the materials and building a plant in which to combine them into a useful product, it was necessary for the Anaconda Co. to spend money for years to promote acceptance by the farmers. Anaconda's Treble Superphosphate fertilizer is now in demand. Containing, as it does, more than 40 percent P_2O_5, the transportation cost per unit of plant food is considerably lower than that of ordinary superphosphate, which carries less than 20 percent P_2O_5.

Mining on Waterloo claim in Montpelier Canyon was carried on intermittently by means of pits and tunnels from 1904 to 1945. At the end of that period, the San Francisco Chemical Co. began an open-pit operation, using power machinery. In September 1947, this activity was suspended indefinitely in order to expand the work at the company's Leefe deposit at Sage, Wyo., another open-pit operation situated 60 miles to the southeast. The phosphate rock produced by the San Francisco Chemical Co. was sold to manufacturers and chemical works. A large tonnage was exported.

The Simplot Co. built a fertilizer plant at Pocatello, Idaho, in 1944 and began mining (by open cut methods) a deposit of phosphate rock 18 miles east of Fort Hall, Idaho. Stripping and mining were done by power shovels. The ore was trucked about 30 miles to the plant. The Union Pacific Railway has constructed a branch from the main line at Fort Hall to the mine; consequently, rail transportation is now available. The normal production rate of 150,000 tons of Simplot superphosphate annually requires 90,000 tons of rock from the mine. In the last few years this company also has produced a large tonnage of raw rock for export.

The three mines mentioned above produced the 900,000 long tons of phosphate rock credited to Idaho in 1947. One of them is now idle, but an equivalent output probably will come from the new Wyoming operation.

GEOLOGY

All of the commercial phosphate rock in Idaho is in the Phosphoria beds, of Permian age. These beds have been wrinkled into north- to northwest-trending folds and are considerably faulted (fig. 2). A characteristic section is shown in figure 3. The Phosphoria formation has been divided into an upper part, called the Rex member, and a lower part, referred to usually as the "phosphatic shale" member. The minable phosphate beds are in this lower member. In Southeastern Idaho, the thickness of the phosphatic shale member ranges from 125 to 230 feet. Northward and eastward, in Montana and Wyoming, this member thins generally to less than 100 feet, whereas southward, in Utah, it thickens to over 230 feet. The phosphatic shales comprise a series of beds of limestone, shale,

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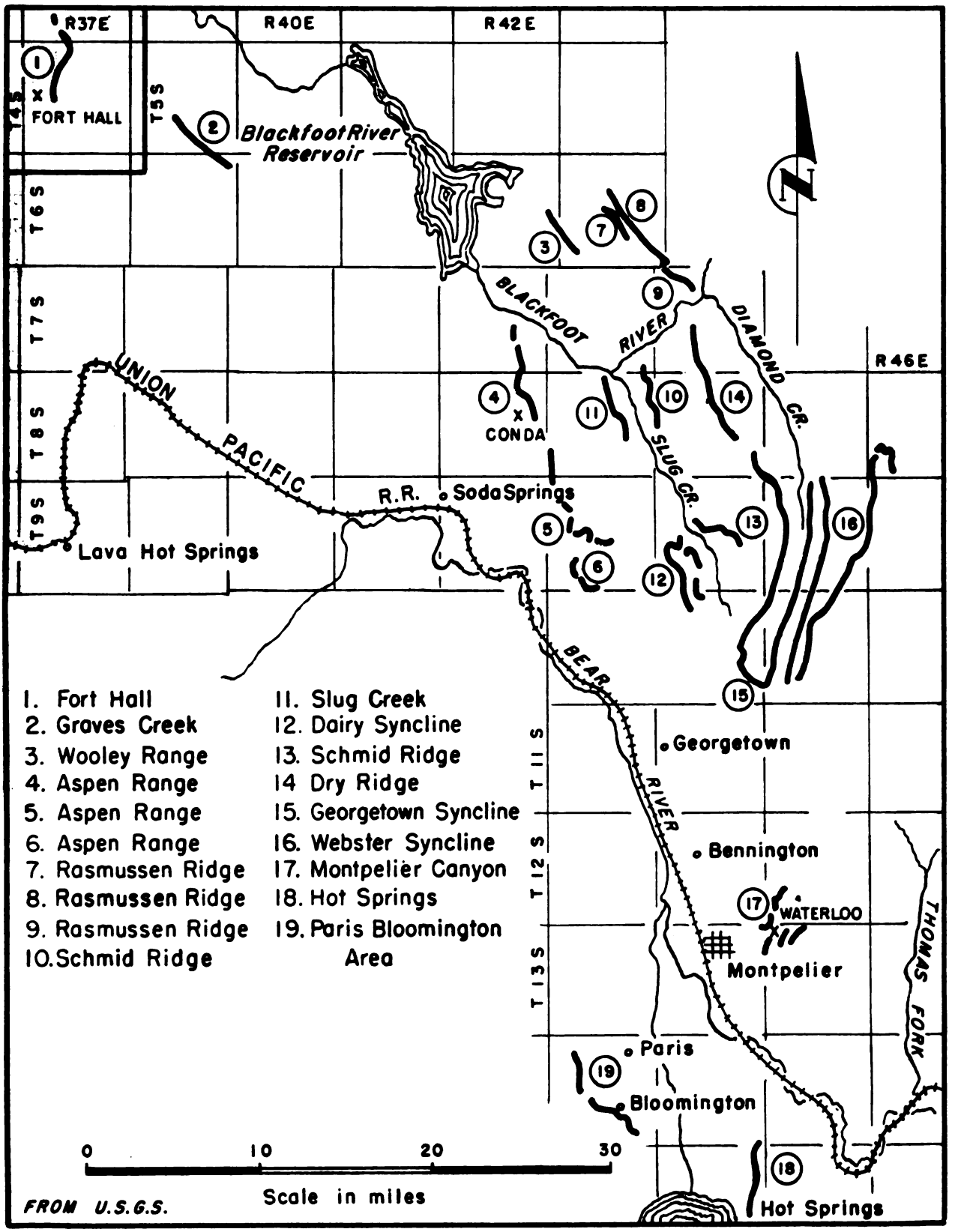

Figure 2.- Principal phosphate deposits of southeastern Idaho.

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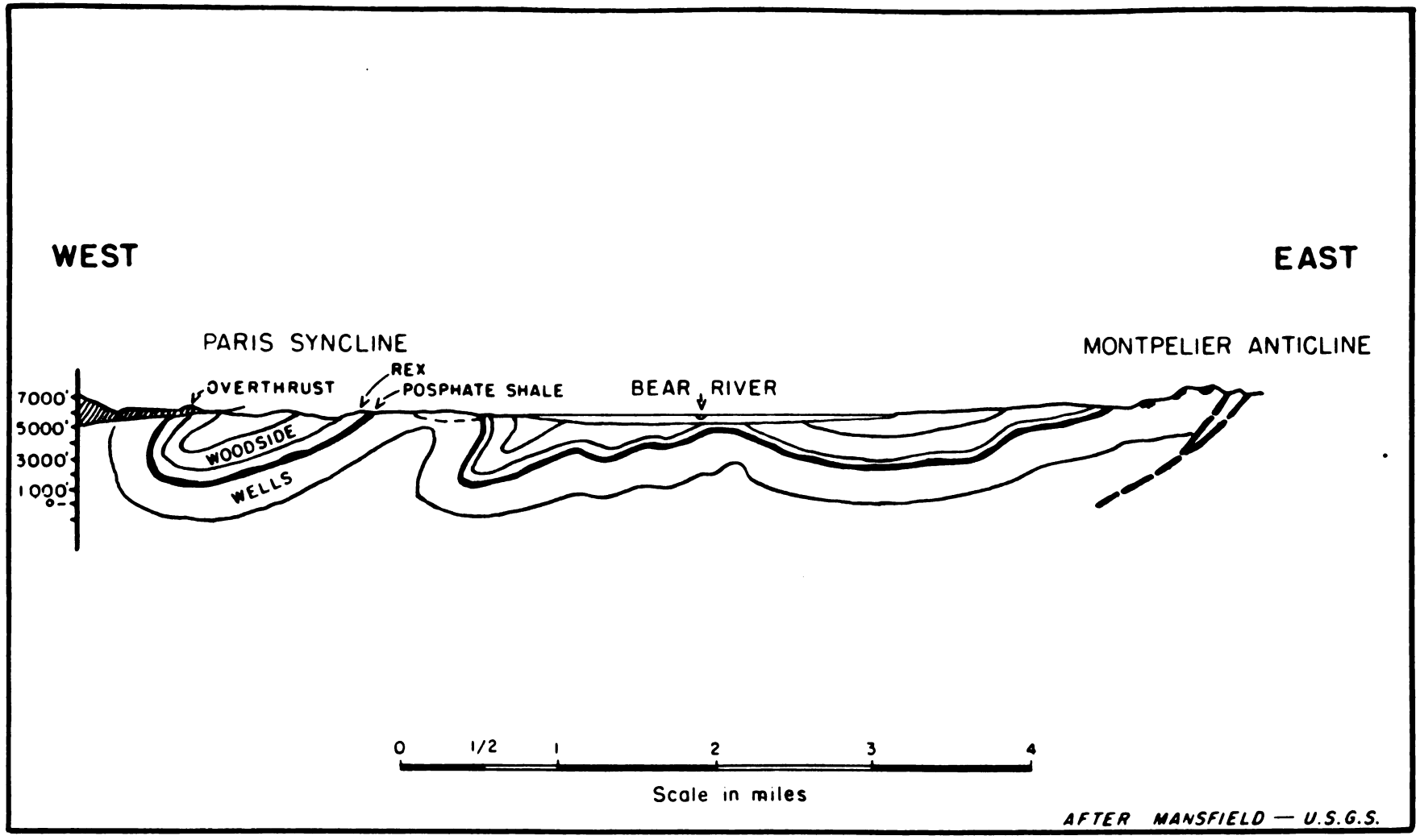

Figure 3. — Section of geological structure, Montpelier, Idaho.

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siltstone, and oolitic phosphate rock, in some of which chert has been developed more or less extensively. Most of the beds contain phosphate, but the most important are two beds of oolitic textured rock, one near the top of the member and the other at or near the base; they are referred to as the hanging wall and footwall beds, respectively. Of these, the footwall oolitic is the more uniformly high-grade over the area. Besides the two principal beds of phosphate rock, each of which ranges in thickness, from 3 to 8 feet thin, nonpersistent seams of oolite are interbedded with the other rocks. Oolitic texture usually, but not invariably, indicates a high phosphorus content. The colors of unweathered phosphatic shale beds are dark brown, dark gray, and black. Weathering leaches out carbonaceous matter and lime, leaving the rock a lighter color and with a higher phosphate content. This leaching is apparent to shallow depths below outcrops. The persistent footwall bed of phosphate rock is in some places overlain by a bed of hard limestone 2 to 5 feet thick, locally referred to as "cap rock." The presence of this "cap rock" immediately over the ore will affect the mining of the phosphate bed by providing a firm hanging wall. The upper or hanging wall phosphate bed is split in places into two or more seams separated by other interbedded rocks.

Besides phosphate the shale member contains other minerals, of which vanadium and fluorine compounds are of most immediate commercial importance. A vanadiferous zone comprising several beds whose combined thickness ranges from 3 to 12 feet has been found by the Geological Survey, usually about 15 feet below the upper bed of phosphate rock. Possibly this zone may be mined for vanadium in the future; the value of the phosphate contained is not high. The data now available indicate that the average grade of the large but undeveloped tonnages in the vanadiferous zone in Idaho and Wyoming will be slightly below 1 percent V_2O_5. Investigation of the vanadium beds underground was made during the war by the Metals Reserve Corporation in Paris Canyon, Idaho, and by the Bureau of Mines in the Salt River Range. Extensive reserves were indicated in both areas.

In unweathered rock, vanadium is present in such minute particles that its mineral form cannot be determined by microscopic examination. The process of weathering has resulted in places in the concentration of secondary vanadium minerals, among which have been recognized hewettite, pascoite, and sincosite.

Although the beds that have the highest vanadium content contain relatively little phosphate (about 8 percent P_2O_5), some of the high phosphorous beds contain very small amounts of vanadium. The Anaconda process of fertilizer manufacture provides for the recovery of vanadium as a byproduct from rock containing from 0.19 to 0.25 percent V_2O_5.

V. E. McKelvey, geologist of the Federal Geological Survey, states that the fluorine-phosphate ratio in samples of Idaho phosphate rock is shown by a large number of analyses to be about 0.1 to 1. The commercial importance of fluorine is growing; hence, any investigation of metallurgical treatment for phosphate should include consideration of the possible recovery of contained fluorine.

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PHOSPHATE RESERVES

Estimates of Total Reserves

To estimate the tonnage of phosphate rock in undeveloped deposits of the area requires the assumption of conditions that may or may not prove later to have been justified.

In 1926, Mansfield[3] computed the reserve in 52 townships of southeastern Idaho. These computations were based upon certain arbitrary assumptions. For example, the depth limit to which reserves were estimated for beds containing 70 percent tricalcium phosphate (32.1 percent P_2O_5) ranged from 0 to 5,000 feet, in direct ratio to the variation of the thickness of beds from 1 foot to 6 feet. The limit of depth also varied with the grade between 0 and 5,000 feet, directly as the variation in tricalcium phosphate content between 30 and 70 percent (13.8 and 32.1 percent P_2O_5). Only the footwall bed was considered in computing the reserve. These assumptions permitted the inclusion of much ore to a depth of 5,000 feet. On the basis of those assumptions, the total reserve in southeastern Idaho was estimated at 4,997,885,000 long tons. The greater part of this tonnage is too deep to be of interest when planning operations at this time.

In an attempt to estimate the total reserve that would be available if rock containing no more than 30 to 40 percent B.P.L. (14 to 18 percent P_2O_5) were included, Waggaman[4] multiplied Mansfield's estimate by 3. Mansfield[5] states that the multiplication is reasonable and cites instances in which this proportion of low-grade rock is known. He considers investigation still too limited, however, to warrant such a broad assumption.

Waggaman's expanded reserve for southeastern Idaho would be 14,993,655,000 long tons of phosphate containing more than 14 percent P_2O_5 lying above a depth of 5,000 feet. At present, these figures are of academic interest only.

Estimates of Mining Reserves

The best means of describing the field briefly and of estimating the tonnage available for mining is to divide it into groups of deposits. Because current commercial interest is limited chiefly to the richest deposits, it is assumed that the minimum average grade minable is 30 percent P_2O_5, and that mines can be worked profitably to a vertical depth of 500 feet below the surface. The average specific gravity of high-grade phosphate rock in Idaho is 2.90; therefore, 12.3:1 is taken as the cubic-foot to long-ton ratio. All of the known deposits of importance in southeastern Idaho are included in the following divisions:

Aspen Range, Nos. 4, 5, 6, 11, 12
Georgetown Canyon, Nos. 3, 7, 9, 14, 15
Webster Range No. 16
Hot Springs, No. 18
Paris Canyon, No. 19
Montpelier Canyon, No. 17
Rasmussen Ridge, No. 8
Schmidt Ridge, Nos. 10, 13
Fort Hall, Nos. 1, 2

(The numbers following district names refer to the numbered deposits shown on figure 2.)

3/ Work cited in footnote 3.
4/ Waggaman, W. H.: Chem. & Met. Eng. 1939, p. 66-68.
5/ Mansfield, G. R., Recent Studies of Reserves of Domestic Phosphate: A.I.M.E. Min. Technol., May 1940.

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Aspen Range

Aspen Range anticline includes the Trail Canyon syncline on the west and the Dairy syncline and Slug Creek syncline on the east side of the range. The mountains rise 2,000 feet above Bear Valley, which lies to the southwest; they extend from the west side of the mouth of Georgetown Canyon northwestward about 20 miles to the Blackfoot River. Slug Creek flows northward on the east side of the range to join the Blackfoot River. Trail Creek rises in the northern part of the range and also flows northward to the Blackfoot. The only roads crossing the Aspen mountains from west to east are in the canyons of Trail Creek and Wood Creek. Both roads lead eastward to the valley of Slug Creek. Soda Springs, the railpoint for this division, is a station on the Union Pacific Railway main line.

The rugged range gives rise to several small streams, most of which disappear before leaving their gulches. In some places a water supply sufficient for mining operations can be obtained by impounding the small streams. Where this is not possible, water may be obtained by pumping from wells or mine workings. Otherwise it will be necessary to pump water from permanent streams. In planning an operations in this part of Idaho, it must be borne in mind that the primary interests of the inhabitants of the region are agriculture and stock raising, and that rights to most of the water have been taken for those purposes. There is the possibility of artesian water being developed in some of the synclinal folds. On the west side of the Aspen Range are a number of large mineral springs carrying calcium carbonate, sodium chloride, and emitting carbon dioxide and hydrogen sulfide gases.

Some timber grows on the higher slopes, but most of the range is covered with aspen groves and brush. Mining timber must be brought in from outside the area.

The average thickness of the phosphate rock in this district is 6 feet. The rock contains more than 30 percent P_2O_5. The formation has been exposed in the workings of the Conda mine, where the phosphatic shale member is 230 feet thick. Both hanging wall and footwall oolitic beds are present here. The vanadium content of the phosphate rock in the oolitic beds ranges from 0.14 to 0.25 percent V_2O_5; this is higher than average for phosphate beds in the field.

At Conda, the dip of the beds ranges from 45° to 90° ; elsewhere in the Aspen area flatter dips will be found. It is estimated that the combined length of outcrop in this division is 23 miles, and that the average dip is between 20° and 25°. A 6-foot bed would contain, to a vertical depth of 500 feet, 40,000,000 long tons. Further assuming that the hanging wall oolite bed is minable grade along 25 percent of the formation, 10,000,000 tons is added for it, bringing the estimate to 50,000,000 tons.

Georgetown Canyon

In this division of the field are included only the deposits that are recognized parts of the great Georgetown syncline. The fold has been traced from Georgetown Canyon northeastward, curving to the west until the strike is

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northwest. Near Blackfoot River reservoir, it is covered by extensive lava flows. The distance from the nose in Georgetown Canyon to the lava cover is more than 30 miles, though the width of the fold is not more than 2 miles. The structure is not a simple trough but has been complicated by folding both across and along the axis, and by transverse and longitudinal normal and reverse faults and possibly by one or more the great overthrusts that have affected this part of Idaho. The nose of the syncline has a re-entrant scallop due to a minor longitudinal anticline. The entire Phosphoria formation is missing in places along the course of the fold. Mountainous topography prevents easy access to the greater part of the division. A road leads from Georgetown, on U. S. Highway 30 N, up Georgetown Canyon, turning eastward over the divide to Wells Canyon, where it joins the Star Valley road. A branch road continues northward into Diamond Creek Valley, the principal drainage basin of the division, and down Diamond Creek Valley to Blackfoot River. This branch is a poor mountain road. The rail point is Georgetown on the Union Pacific Railway.

There is more fir and pine timber standing in this division than there is in most of the others, though here, too, aspen is the most widely distributed tree.

The phosphate bed was developed to some extent by claim holders in Georgetown Canyon, but the greater part of the outcrop has not been investigated below the surface. A large part of the area is still unsurveyed by the Bureau of Land Management. An estimate that 44 miles of outcrop exist on the Georgetown syncline is reasonable. The observed dips are not as steep as those in the Aspen Range. These low dips may be expected to flatten with increasing depth; hence, an average dip of 40° is assumed. A total reserve of 87,000,000 long tons is estimated on the basis of these data.

Webster Range

The phosphate beds in this division are those of the Webster syncline, a fold that parallels the Georgetown syncline on the east. The limbs of the Webster syncline diverge northward, giving the fold greater width in that direction. The Bannock thrust fault traverses Crow Creek Canyon; a branch of it has been traced up Sage Valley. The bottom of the syncline may be cut off by this fault, but the phosphate beds would be unaffected by it at a depth of 500 feet below the surface. The surface of this area is very rugged; the Preuss Range and Snowdrift Mountain are in the southern part; the Webster Range and Freeman Ridge are in the northern part. Crow Creek flows northeasterly from the south end of the syncline. The Montpelier-Star Valley road is in the Crow Creek Canyon. A secondary road branches northward through Sage Valley. From Sage Valley, a poor road leads up Smoky Creek and crosses the outcrop of the east limb of the syncline. The Georgetown Canyon road crosses the syncline at its narrowest part and descends Wells Canyon to join the Star Valley road on Crow Creek. Except here, the western limb of the Webster syncline is difficult of access.

The mountain slopes in this division are mostly bare of timber, though some trees grow on the east side of the Webster range. Several ranches and range camps are in Crow Creek Canyon. The rail point for the area is Montpelier, about 30 miles by road from the upper end of Sage Valley.

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Little developing has been done in this division. Some shallow trenches, however, have indicated the presence of oolite beds with high phosphate content. Mansfield is of the opinion that the phosphate beds may be presumed to be present in the Webster syncline and that their thickness and volume are comparable with those of neighboring areas. The length of outcrop is estimated at 32 miles. A 5-foot bed dipping at an average slope of 40° would indicate 52,800,000 tons.

Hot Springs

This division includes only one deposit; cropping on the Bear Lake plateau near the north end of Bear Lake, it strikes northward and dips steeply to the west. The position of the phosphate bed may be determined easily by tracing the relatively prominent outcrop of the Rex chert along the low, bare hills. Some prospecting has been done. Mining development was begun at one place, but no phosphate rock was ever produced. The proximity of Bear Lake would solve the problem of water supply for operations but might prevent deep mining by maintaining the ground-water level.

A poor road leads from Hot Springs north, near the outcrop, to Dingle (8 miles south of Montpelier), a village on the west side of Bear River.

Assuming that the formation has an average dip of 60° and an average width of 5 feet, the estimated tonnage available to a depth of 400 feet below the 4.5 miles of outcrop would be 4,400,000 tons.

It is probable that in mining the Bear Lake deposit, a drainage tunnel driven as near lake-water level as possible would prove the most economical means of access to the ore. Such a tunnel would be several thousand feet long, whereas the outcrop is easily accessible. Pumping costs, however, would be eliminated by tunneling if development were kept well in advance of stoping.

Paris Canyon

The Paris-Bloomington area on the west side of Bear Lake Valley is underlain by the Paris syncline, an overturned fold whose steeper west limb is covered in places by the Bannock overthrust. The east limb has a flatter dip; consequently it crops out on lower land to the eastward, where it has been covered by wash from the Bear Lake Mountains and by the lake deposits in the valley. Although outcrops are somewhat scant, both limbs of the syncline have been opened in Paris Canyon; both limbs, therefore, have been included in the estimate.

Sufficient prospecting has been done to show the presence of the oolitic phosphate beds in Bloomington Canyon, south of Paris Canyon, and in Slight Canyon to the north. Indications of the outcrop of the western limb have been traced 5 miles north from Bloomington Creek; the deposit may extend much farther. This west side of the fold is more faulted and crushed than the east limb; therefore, it may be more difficult to mine. Furthermore, the percentage of recovery from the west limb may be less.

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An unsuccessful mining venture produced some phosphate rock from the west limb in 1920. This phosphate contained vanadium. Knowledge of the presence of vanadium later influenced the selection of this vicinity for an effort by the Metal Reserve Board, through the agency of the Wyodak Coal Co., to provide an emergency supply of vanadium ore. The highest vanadium content had been shown elsewhere to be in a series of beds near the top of the phosphatic shale member. Investigation was therefore directed at this vanadiferous zone in the east limb of the syncline. Enough exploration and development was completed to indicate the presence of a large tonnage of rock containing about 0.9 percent V_2O_5 and to permit the inference of a much larger tonnage containing about 0.6 percent V_2O_5.

If it is assumed that the average dip of the west side is 50° and that of the east side is 30°, 17,600,000 tons may be estimated in a 5-foot bed 5 miles long. This estimate does not include the high vanadium, low phosphate-bearing beds mentioned above.

Montpelier Canyon

The Montpelier-Star Valley road is in Montpelier Canyon; branches lead from it to Thomas Fork and to other valleys to the east. Montpelier Creek furnishes the water supply for the town of Montpelier.

The phosphate beds on Waterloo Hill in Montpelier Canyon are the remnants of a badly folded west limb of an anticline. Before mining was started, erosion had removed much of the overburden and, in places, all of the phosphate. The hard overlying "cap rock" limestone protected much of the phosphate from removal by weathering, leaving the footwall oolite bed dipping with the slope of the west side of Waterloo Hill.

From 1904 to 1945, phosphate was mined intermittently on Waterloo Hill; an estimated 20,000 tons was produced during that time. Beginning in June 1945, the San Francisco Chemical Co. shipped 675,000 tons of rock containing 32 percent P_2O_5 before suspending operations in September 1947. Probably an equal amount of rock remains on Waterloo Hill above the creek level.

Northward from the Waterloo Hill workings, the outcrop of the beds may be traced across the creek, up the north side of the canyon, and over the first ridge, where it is lost in a faulted area. This northern part of the deposit has many prospecting pits along the outcrop. Before 1925, a small production of phosphate came from a lessee's operation on this section of the beds. There should be available, under 1-1/4 miles of outcrop of a bed 6 feet thick, dipping 40°, 2,400,000 tons of phosphate rock.

Rasmussen Ridge

Rasmussen Ridge was formed by the Snowdrift anticline that separates the northern end of Georgetown syncline, to the southwest, from Lane's Butte syncline, to the northeast. The phosphate deposit considered in this division is in the west limb of Lane's Butte syncline. The east limb of this fold has not been included because there is no outcrop.

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The outcrop of the west limb is exposed throughout a distance of 7 miles along the northeast flank of Rasmussen Ridge, from the junction of Diamond Creek with the Blackfoot River to the valley of the Little Blackfoot River. The area is rugged and remote. A limited amount of investigation of the Phosphoria formation indicates that the footwall is at least 6 feet thick; it contains more than 32 percent P_2O_5. The tonnage estimate for this division is 11,700,000.

Schmidt Ridge

The Schmidt syncline is under Schmidt Ridge, between Slug Creek and Dry Creek, south of the Blackfoot River. The Phosphoria beds have been much dislocated by both longitudinal and cross faulting. For several miles the outcrop of the west limb disappears under the wash of Slug Creek Valley. The east limb outcrops only in short segments; most of it is missing. When lower-grade rock is wanted, Schmidt syncline possibly will be exploited, but no bed of rock assaying as much as 30 percent P_2O_5 has been found there thus far; consequently, no tonnage is estimated for this division.

Fort Hall

This area is separated from the most northwesterly of the foregoing divisions by a distance of 40 miles but properly is included with them in a summary of phosphate beds in southeast Idaho. Topography of low relief affords easy access to the area by road from Fort Hall, a station on the Union Pacific Railroad. The phosphate land is on the Fort Hall Indian reservation. With the consent of the Indians, a lease was granted to the Simplot Fertilizer Co. in 1944.

The beds of the Fort Hall deposits have been folded and faulted into a complex structure. Transverse normal and reverse faults have hacked the northern part of the deposit into a number of blocks, leaving short segments of the phosphate beds in various disjointed attitudes. The southern part of the deposit parallels a reverse fault, which cuts off its downward extension at a shallow depth.

The Fort Hall mine is the only one in Idaho where phosphate rock containing less than 30 percent P_2O_5 is being mined. Overlying the 6-foot bed of high-grade rock is a stratum of shale ranging from 8 to 15 feet in thickness, which contains about 25 percent P_2O_5. This is being selectively mined for shipment to a smelter designed to produce elemental phosphorus.

In estimating the tonnage in the 6-foot bed of oolite high-grade rock, it is assumed that the average dip of the formation is 30° and that the length of outcrop is 4 miles. An assumption that the deposit can be mined to a depth of 200 feet is conservative. Under these conditions, a reserve of 4,100,000 long tons is inferred.

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Summary

The estimates described in the foregoing sections are summarized below:

	Long tons
Aspen Range	50,000,000
Georgetown Canyon	87,000,000
Webster Range	52,800,000
Hot Springs	4,400,000
Paris Canyon	17,600,000
Montpelier	2,400,000
Rasmussen	11,700,000
Fort Hall	4,100,000
	230,000,000

These estimates include only those deposits whose outcrops give evidence of continuity throughout considerable distances. They were based upon previously published information and maps; they did not have the benefit of the results of Geological Survey work now in progress, which will certainly modify the data formerly available. Other outcrops in southeastern Idaho have been reported. Field work now being conducted by the Geological Survey will investigate these reports and also will investigate other areas believed to contain phosphate deposits. Additional large deposits may be discovered.

MINING METHODS

Prospecting and Locating

A prospective operator entering the western phosphate field is not obliged to search for a deposit to investigate. More than 40 years' work by the Federal Geological Survey has resulted in the mapping of the phosphate formation; much study has been devoted to its geological structure. The problem is to choose among known ore bodies the one most suitable for the purpose. If the location chosen is on public land, a lease may be applied for. Information as to leasing may be obtained from the Bureau of Land Management, Interior Bldg., Washington 25, D. C., or the regional administrators at 3265 Stapleton Bldg., Billings, Mont., Federal Building, Salt Lake City, Utah, or Swan Island Station, Portland, Oreg. Detailed investigation of any deposit has not been made by any Government agency; this will have to be undertaken by the lessee.

Strip Mining

The cheapest method is strip mining, but the necessary combination of circumstances for its employment is not often met in southeastern Idaho. The chief requirements are that the bed have a low dip that approximates the slope of the surface over a large area and that it lie at a shallow depth. Such a condition is shown on the east side in figure 4. Fort Hall mine and Waterloo mine in Idaho and Leefe mine in western Wyoming have been worked as stripping operations.

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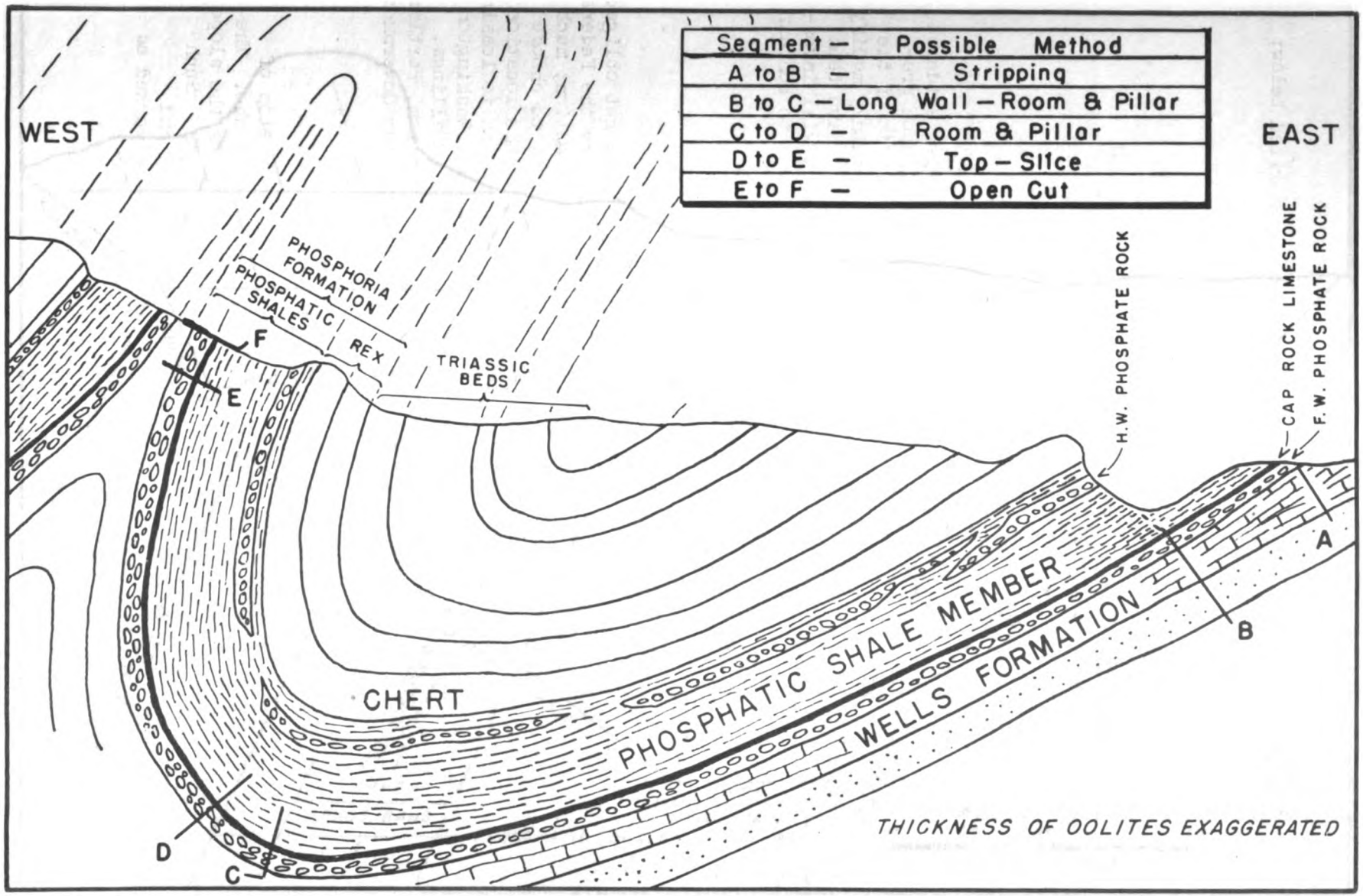

Figure 4 — Mining methods suitable to Idaho phosphate beds.

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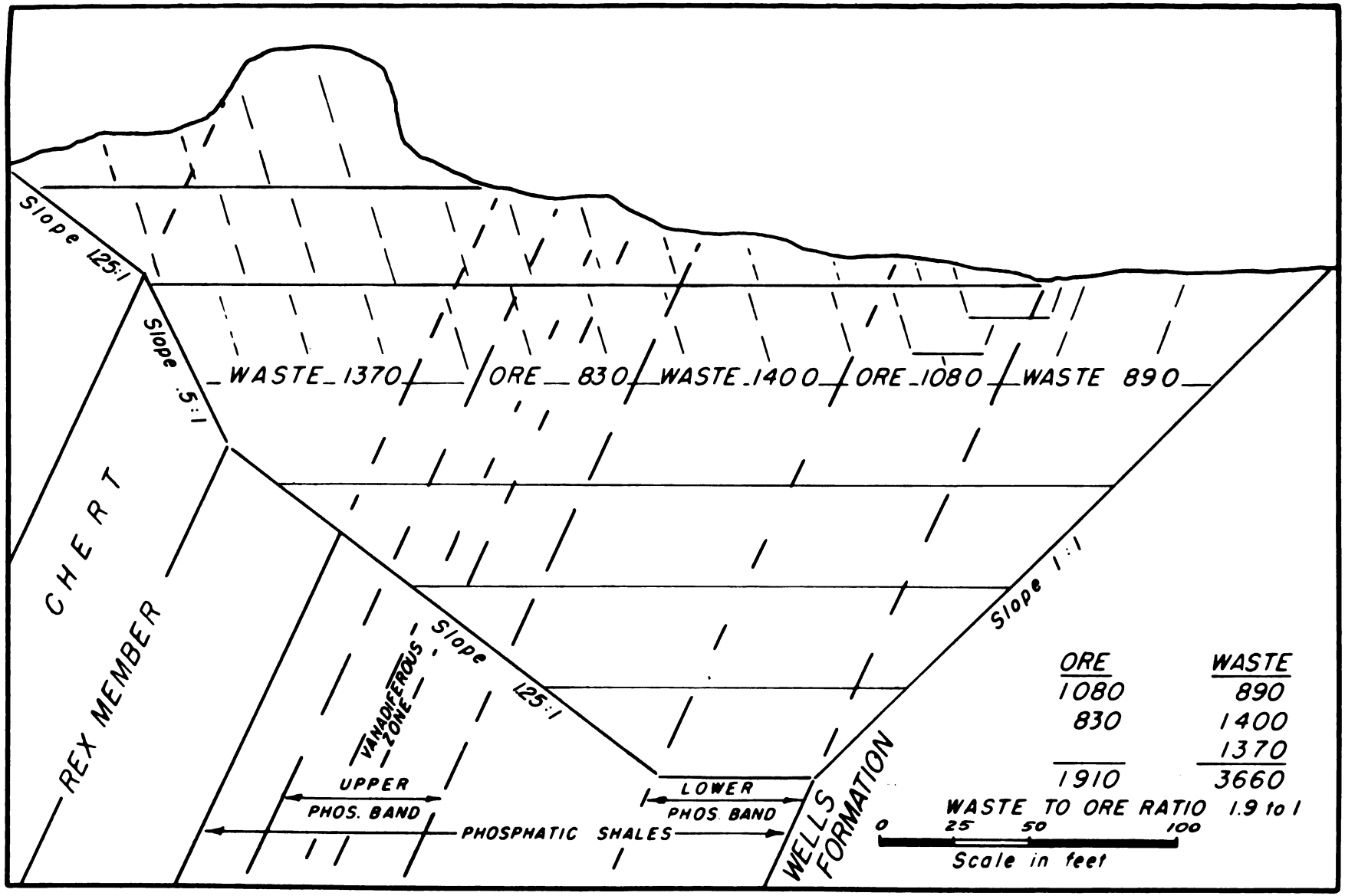

Figure 5. — Section of phosphoria beds mined by open-cut, southeastern Idaho.

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In many strip mines the overburden is removed from a section of ore; then the ore is mined, after which the overburden stripped from the next section of ore is piled on the footwall, from which the ore of the previous section has been mined. In this way, haulage is reduced on the amount of overburden that can be so backfilled.

At the Fort Hall mine, the 6-foot bed of high-grade phosphate rock is overlain by shale beds containing 25 percent P_2O_5. The Simplot Co. found a market for this rock. The procedure, therefore, is to strip the waste overburden from the 25-percent shale, then mine and store the shale on low-grade ore dumps, leaving the high-grade phosphate ready for mining.

Open-Cut Mining

The open-cut method is here distinguished from strip mining by its application to steeply dipping beds or to those deposits whose waste-to-ore ratio is high, or to the mining of wide ore zones. Production from wide ore zones in the Idaho phosphate field is dependent on the profitable utilization of low-grade rock. If one or more 50-foot zones of 20 percent phosphate were to be mined, a considerable volume of ore could be dug economically with power shovels in an open-cut operation along the outcrop of the formation. If the entire width of the phosphatic shales could be mined, as illustrated in figure 5, a very large volume of minus 20 percent rock would be available to open-cut mining at very low unit costs.

Underground Mining

The phosphate beds in most of the known Idaho outcrops dip steeply; in places, the folds have been overturned, bringing into the hanging wall beds that normally are in the footwall, and vice versa. Eastward in Wyoming and northward in Montana, beds of the Phosphoria formation assume gentler slopes, but both thickness and phosphate content decrease. When low-grade rock is needed, it is probable that some of the Wyoming and Montana deposits can be mined by stripping or by open-cut methods.

In Idaho, all but a few deposits must be mined by some underground system. Because of the low unit value of the product, the mining system used must permit production at a low unit cost.

Shrinkage Stoping

In some places where the beds lie at a steep angle, the walls may be strong enough to permit shrinkage stoping. At Cokeville, Wyo., where the deposit was mined in this manner, the walls in some stopes are still standing, although the mine has been idle for years. This is the cheapest method of underground mining for deposits of moderate width. Unfortunately conditions suitable for shrinkage stoping will not be encountered frequently in the phosphate beds; in most places the walls will be too weak. Furthermore, it is possible that the broken ore would be difficult to draw from the bottom of the stope, where it would be under increasing pressure as breaking progressed upward. Experience on this point is conflicting. The United States Phosphate Co., operating a mine at York Canyon in the Sublette Ridge, Wyo., in 1915, had trouble with the rock

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sticking in chutes. An unpublished report states "The rock packs badly." The mine was comparatively dry. At Conda mine, Idaho, however, all the ore broken is passed through raises down to the main haulage level, where it is drawn through chutes to load trains. This indicates that the rock at Conda does not pack badly.

Square-Set Stoping

Most of the southeastern Idaho phosphate deposits that are to be mined by underground methods will require that the walls be supported to within a short distance of the face and that the stopes be filled shortly after removal of the phosphate rock. Both of these requirements are met by standard square-set stoping. The relatively high cost of square-set stoping may render it unusable in these deposits, however. A stoping method that is, essentially, a modified form of square-set stoping has been developed at the Conda mine. This method uses about the same amount of timber as would a square-set method, but it eliminates or greatly reduces the cost of stope filling; it is described in the following section.

Top Slicing

The phosphate beds now being mined at Conda are about 7 feet wide; they dip 45° to 90°. If the walls had been strong, much of the deposit would have been suitable for shrinkage stoping. Instead, the walls are soft and weak; consequently, a top-slicing method is used. Starting near the outcrop, the bed is mined down the dip in successive horizontal slices, each 6 to 10 feet deep. The slices are timbered closely. Because the walls are weak enough to cave easily, it is possible to maintain a timber mat and caved fill in close contact with the back of the unbroken ore. Top slicing permits clean and complete mining of the rock but requires much timber; it is not a low-cost method when applied to narrow ore bodies.

Conda is the sole underground operation producing phosphate rock in the Idaho field. More than 25 years of experience at Conda proves that weak-walled phosphate beds can be mined by top-slicing, notwithstanding its high cost.

Cut-and-Fill Stoping

Cut-and-fill stoping could be used in some of the steeply inclined beds but probably would be too expensive for phosphate mining. In many, if not most, of the potential phosphate-producing districts it is doubtful if the stopes could be kept open without timber support until waste fill could be introduced. In most districts the wall rocks adjacent to the phosphate beds are strata of shale and siltstone with intercalated limestone. Such wall rocks probably will make it necessary that timber support be kept close to the face.

Room-and-Pillar Methods in Flat or Gently Pitching Beds

In those localities where a bed of limestone "cap rock" immediately overlies the phosphate bed, as at Waterloo mine in Montpelier Canyon, the use of a room-and-pillar method will be possible in the more flat-dipping sections of the deposit. The determination of room widths and procedure in robbing pillars must await the opening of stopes.

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Long-Wall Methods in Flat or Gently Pitching Beds

The underground mining of phosphate beds 4 to 8 feet thick, dipping at low angles, presents the same problems as coal mining, without the coal mines' special hazards of fire and explosion. A longwall system of mining, as developed for coal, would be advantageous. Longwall retreating requires a greater initial investment for development than longwall advancing, but its use eliminates the maintenance of haulageways through caved areas and permits much better ventilation of the faces. The successful use of the method depends largely on the nature of the hanging wall and its method of caving; it must not break down too close to the face. Extensive faulting would be troublesome; possibly it would render the method unusable. Whether or not longwall methods will be applicable to the Idaho phosphate beds cannot be stated until more is known about the conditions that will be found.

Caving Methods

Caving methods are not applicable to the mining of narrow bodies. Their application to the phosphate beds depends, therefore, upon the future development of uses for the lower-grade phosphate rock that occurs in wider beds.

Detailed sampling of the entire width of the phosphatic shale member by the Geological Survey has indicated a band 50 feet thick near the base, including the footwall oolite bed, that would average 20 percent P_2O_5, and possibly another of equal thickness and grade, including the hanging-wall oolite, near the top of the member. The mining of these widths must await improvements in metallurgy or development of an economic process for the beneficiation of low-grade rock.

General Discussion of Mining Methods

Figure 4 shows a generalized section through an overturned anticlinal fold and a syncline. Assume that only the narrow high-grade beds are to be mined. The upper oolite bed in Idaho is not as regular in thickness or in phosphate content as the lower bed. Discussion, therefore, will be confined, chiefly, to the lower bed. Where the upper bed is of commercial value, it will be mined in advance of the lower bed by the same methods, except that a thick bed of chert overlying the upper bed reduces the desirability of mining the outcrop by stripping.

In figure 4, it is shown that erosion of much overlying material from the lower oolite near the outcrop A, of the east limb of the syncline, makes strip mining the best method to use as far down the dip as some point B, where the necessary volume of stripping becomes too great.

From point B to some limit between points C and D, a longwall or room-and-pillar system will be suitable. Either of these methods should begin at B and retreat to the trough of the syncline or to the limit of mining. If room-and-pillar stoping is used, pillar robbing should follow room mining down the slope, allowing the hanging wall to subside after the recovery of the maximum tonnage consistent with safety. The dip of the formation is too low for broken rock to move on it by gravity alone. Transportation to main haulage may be effected by conveyor belt, gravity plane, rope tram, or shaking chutes.

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The main haulageway should be in the Wells limestone or quartzite under the Phosphoria formation. If the syncline is not too deep, the haulageway could be in the trough of the syncline.

On the west limb of the syncline, the beds steepen sharply into the east limb of the overturned anticline; near the surface they assume a reverse dip. Strong, unbroken walls in this part of the deposit would render shrinkage stoping possible, but such a condition is unlikely over a large area where folding has been so intense. The method chosen probably would be top slicing or square setting between the outcrop F and some point between C and D, below which the body would be mined by one of the other stoping systems.

In some places it might be of advantage to mine the steep outcrop F by open cut down to some point E, as, for example, where faulting or folding has brought two or more segments of the ore bed close together.

It has been stated in the section on "Phosphate Reserves" that the southeastern Idaho deposits comprise a reserve of 230,000,000 tons of inferred ore containing 30 percent P_2O_5 within reasonable mining depth. Insufficient knowledge of the attitudes of the beds below their outcrops precludes an accurate estimate of the tonnage amenable to each of the several methods of mining. It is probable, however, that few deposits will be found suitable for strip mining on these few deposits the method generally can be applied to less than 25 percent of the total tonnage in the 6-foot bed above the assumed mining limit of 500 feet.

Allowing that 30,000,000 tons might be mined by stripping, there would be 200,000,000 tons to be mined by top-slicing, square setting, or combinations of the two in steep beds and by room and pillar, longwall, or their modifications where beds are flatter. The proportion of the reserve to be worked by each of the two classes of stoping can be determined only after development.

Inspection of the section in figure 3 shows most of the Phosphoria formation to be in wide folds with gently inclined beds. The flattened bottoms of the synclines are below the mining limit. Four outcrops are shown on the section (the west limb of the Paris syncline is not everywhere covered). Of these, two are steep and two have moderate dips. The beds with moderate dips contain more ore than the beds with steep dips. Assuming the section to be typical of the field, more than 100,000,000 tons will be amenable to low-dip stoping and less than 100,000,000 tons to high-dip stoping.

COSTS

The following very rough estimates of the probable costs of mining high-grade phosphate rock 6 feet thick have taken into account the present (1948) high wage scales and cost of materials.

Strip Mining

Strip mining with power machinery is the most economical means of mining shallow, gently dipping phosphate beds near the outcrop. The application of the method requires that the dip of the formation be at a low angle and that the surface have approximately the same slope. It is assumed that the limit of depth of the pit will be 100 feet below the surface. Under these conditions, the direct mining cost per ton should be approximately $2.

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Open-Pit Mining

If the two wide bands of rock containing 20 percent P_2O_5, previously referred to, should become useful, then the vanadium ore of the vanadiferous zone, which is included in the upper band, would be available at a low mining cost. Possibly, the entire width of the phosphatic shale member could be mined selectively by an open-cut operation. Figure 5 illustrates the procedure in mining wide, steeply-dipping beds by this method. Probably the direct mining cost of a well-equipped and well-managed open-cut operation could be reduced to less than $1 per ton.

Underground Mining

The discussion of mining methods presented earlier in this report indicated that square-set stoping or the top slicing method that was developed at the Conda mine are the only methods that definitely may be considered to be generally applicable to the steeply dipping parts of the high-grade phosphate deposits of southeastern Idaho. Room-and-pillar or longwall methods were indicated to be the methods most likely to be applicable to the flat-lying parts of the deposit. In the soft ground that usually will be found, any of these methods will require the use of large amounts of timber. Unless cheaper methods can be developed, it must be assumed that the direct cost of underground mining in the steeply inclined beds will approximate $4 per ton of rock. Stoping in areas of low dip will be more costly, probably near $5 per ton.

If the wide deposits of lower-grade rock were to be mined by underground methods, much lower costs could be obtained. Caving methods probably could be applied. It is not likely, however, that any attempt will be made to mine the low-grade ores by underground methods until most of the ore that can be mined by open-pit methods has been exhausted. A discussion of underground mining methods applicable to the low-grade ores would be premature at this time.

SUMMARY OF MINING METHODS AND COSTS

The foregoing preliminary estimates of the probable methods and direct costs of mining phosphate rock in southeastern Idaho are summarized as follows:

Attitude of deposit	Approximate thickness, feet	Approximate content P_2O_5, percent	Mining method of most general application	Approximate cost/ton	
				Rock	P_2O_5
Low dip (near surface)..	6	30	Strip mining	$2	$7
Low dip (deep).....	6	30	Room-and-pillar	5	16
Low dip (near surface)..	50 1/	20	Strip mining	1	5
Steep dip (near surface or deep).....	6	30	Square set or top slice	4	13
Steep dip (near surface)	50 to 200 1/	20 to 12	Open pit	1 to 0.50	4 to 8

1/ Will be applicable only when low-grade rock becomes of general commercial value.

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The advantage of strip mining is shown in the wide difference in cost per ton of stripping and underground stoping. In stoping, the lowest cost may be expected where the beds are steep enough so that the broken rock may be moved by gravity.

More detailed descriptions of the various mining methods are given in the "Mining Engineers' Handbook," published by John Wiley and Sons, or in Bureau of Mines Bulletin 390, "Stoping Methods and Costs." The latter publication is out of print but should be available at the libraries of the larger cities.

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